Single Image Dehazing Based on Adaptive Histogram Equalization and Linearization of Gamma Correction

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***Abstract*— Visibility of outdoor images is usually limited due to haze, dust, smoke and other particles in air. Visibility limit can cause many difficulties for activities of transport, rescue, oceanography etc. Hence, image dehazing is very necessary. In this paper, we propose a single image dehazing method based on combination of adaptive histogram equalization, HSV color model and linearization of Gamma correction. In the experiments, we test the proposed method on hazy images of the TAU dataset. To assess dehazing quality, we utilize NIQE metric and compare to other dehazing methods. The results confirm that the proposed method dehazes effectively and can compete with other state-of-the-art dehazing methods.**

Keywords—Dehazing, Defogging, Image Restoration, Image Processing, Histogram Equalization, HSV, Gamma Correction.

I. Introduction

Image processing has a wide range application in many fields of life such as medicine [1, 2], automation [3], transport [4], remote sensing [5] etc. In problems of image processing, image restoration [6, 7, 8] plays a vital role, because it improves accuracy, performance for other postprocessing tasks.

Dehazing is a subfield of image restoration, in that, images are degraded by haze, dust, smoke etc. The factors limit visibility. In transport, limit of visibility can cause serious crashes. Basically, haze has two effects on the captured image: it reduces the signal of the viewed scene and it adds auxiliary components to the image, called ambient light or airlight.

The hazy image degradation increases by distance from the camera, because scene radiance decreases and airlight magnitude increases [9]. The degradation reduces visibility.

There is a variety of approaches to solve the dehazing problem: capture multiple images under various weather conditions [10], or two images with different polarization states [11] and single image dehazing methods [9, 4, 12, 13]. In this paper, we only focus on single image dehazing.

He et al. proposed a single image dehazing method using dark channel prior [13]. Zhang et al. proposed another dehazing method based on combination of Retinex and Haar wavelet transform. Although they use Haar wavelet transform, we can extend to other wavelet transforms such as Coiflets, Symplets etc. easily. Another well-known single dehazing method integrated in MATLAB was proposed by Dubok et al. The Dubok method was developed based on image entropy and information fidelity. In recent years, a non-local image dehazing method was proposed by Danna et al. Abovementioned methods contains many parameters, and for some methods from them, we need to estimate image prior before dehazing.

In this paper, we propose a simple single image dehazing method without knowing image prior. The method is a combination of adaptive histogram equalization, HSV color model and linearization of Gamma correction.

In the experiments, we use blind image quality assessment metric – NIQE metric – to evaluate dehazing quality, because ground truths are not given. Otherwise, we also compare dehazing result of the proposed method with other state-of-the-art dehazing methods.

The rest of the paper is structured as follows. Section II presents the dehazing problem and the proposed dehazing method. Section III presents experimental results and comparison. Finally, Section IV concludes.

II. Dehazing Problem and Proposed Method

A. Dehazing problem

Let $\mathbf{I}(\mathbf{x}), \mathbf{J}(\mathbf{x}) \in \mathbb{R}^3$ be original and hazy colorful images (in RGB space), respectively, where $\mathbf{x} \in \Omega \subset \mathbb{R}^2,\ \mathbf{x} = (x, y)$.

The well-known hazy image formation model is:

$$\mathbf{J}(\mathbf{x}) = t(\mathbf{x})\mathbf{I}(\mathbf{x}) + \big(1 - t(\mathbf{x})\big)\mathbf{A}, \qquad (1)$$

where $\mathbf{A}$ is atmospheric light and describes the intensity of the ambient light; the direct transmission of the scene radiance, $t(\mathbf{x})\mathbf{I}(\mathbf{x})$, corresponds to the light reflected by the surfaces in the scene and reaching the camera directly, without being scattered; the airlight $\big(1 - t(\mathbf{x})\big)\mathbf{A}$ corresponds to the ambient light that replaces the direct scene radiance; $0 \le t(\mathbf{x}) \le 1$ denotes the transmission along the camera ray at each pixel.

The goal of the dehazing problem focuses on recovery of $\mathbf{I}(\mathbf{x})$ from a given hazy image $\mathbf{J}(\mathbf{x})$.

B. Adaptive Histogram Equalization and Proposed Method

Adaptive histogram equalization [14, 15, 16] is an image contrast enhancement method. The method operates on small regions of the image (i.e. tile). The contrast transform function for each tile is computed and will be applied for the tile to enhance contrast. Hence, the histogram of the output region approximately matches the histogram specified by a distribution, such as uniform, Rayleight or exponential. Finally, the neighboring tiles are then combined using bilinear interpolation to eliminate artificially induced boundary.

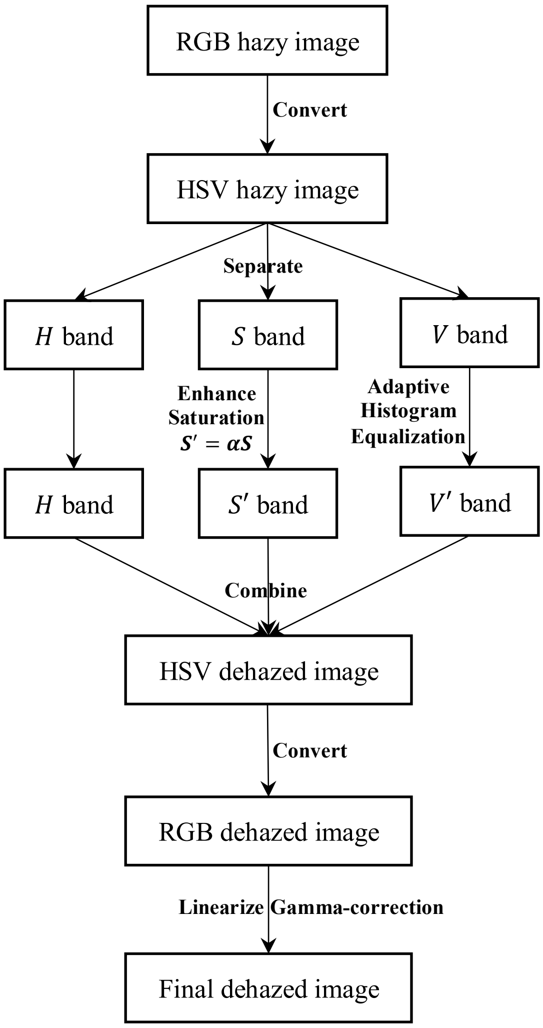

Fig. 1. Workflow of the proposed dehazing method

In order to apply the adaptive histogram equalization to the dehazing problem, first step, we transform the RGB-color image to the HSV color space [17]:

$$H = \begin{cases} 0, & \Delta = 0 \\ 60\left(\dfrac{G-B}{\Delta} mod\ 6\right), & C_{max} = R \\ 60\left(\dfrac{B-R}{\Delta} + 2\right), & C_{max} = G \\ 60\left(\dfrac{R-G}{\Delta} + 4\right), & C_{max} = B \end{cases},$$

$$S = \begin{cases} 0, & C_{max} = 0 \\ \dfrac{\Delta}{C_{max}}, & C_{max} \neq 0 \end{cases}, \qquad V = C_{max},$$

where $C_{max} = \max\{R, G, B\}, C_{min} = \min\{R, G, B\}, \Delta = C_{max} - C_{min}$; R, G, B are pixel intensity value of red, green, blue channel, respectively; H, S, V are pixel intensity value of hue, saturation and value (lightness) component, respectively.

Second step, the adaptive histogram equalization method will be applied for the value band V. We only process the band V, because haze mainly focuses on this band.

In third step, since adaptive histogram equalization reduces saturation of the dehazed image, we must improve the saturation band: $S' = \alpha S, \alpha > 0$.

Fourth step, we combine all bands of the HSV image and convert to RGB color space.

Finally, we linearize gamma-correction [18] to acquire the final dehazing result:

$$f(u) = \begin{cases} -f(u), if\ u < 0 \\ cu, if\ 0 \leq u < d, \\ (au + b)^{Y}, u \geq d \end{cases}$$

where u and f are pixel intensity values of each red/green/blue channel of the dehazed image in the RGB color space and the dehazed image in the standard RGB color space, respectively; $a = \frac{1}{1.055}; b = \frac{0.055}{1.055}; c = \frac{1}{12.92}; d = 0.04045; Y = 2.4$.

The workflow of the proposed dehazing method is presented in Figure 1. We must notice that, the adaptive histogram equalization is a linear transform and we only process the S band and the V band, so complexity of the proposed method is $O(2 \times m \times n)$, where m, n are number of pixels by the image height and the image width, respectively.

III. Experimental Results and Discussions

We implement the proposed dehazing method on MATLAB 2018b. The computing system configuration: Windows 10 pro, 4GB RAM, CPU core i5.

For the proposed dehazing method, we set parameter α to 1.65. Implementation of other dehazing methods are given by Authors. We keep default parameters as in their programs.

A. Image Restoration Quality Assessment Metrics

Because we test the methods directly on hazy images without ground truth, we must use the blind/referenceless image quality assessment metrics. The NIQE [19] is a well-known metric. The NIQE metric was proposed by Mittal et al. and the metric is based on the principle of the certain regular statistical properties of the natural image. This metric compares a given image to a default model computed from image of natural scenes. So, this metric is more effective on natural images (real images). The NIQE is handled via three steps:

- Developing a natural statistics scene model from the input natural image.
- Extracting statistical features from corpus of natural image.
- Mapping features extraction to the quality score that is called NIQE index.

The smaller value of NIQE, the better perceptual quality. Note that, perceptual quality may be not same to quality assessment by human vision.

B. Synthetic Images and Test Cases

We test the methods on hazy images of the common TAU dataset *http://www.eng.tau.ac.il/~berman/NonLocalDehazing*. All images are stored in RGB color. We select 12 images: alberta 1, alberta 2, alberta 3, canon, cones, factory, forest, grain, pumpkins, stadium, swan and train for the test as in Figure 2. All images are in JPEG format.

Fig. 2. Several selected hazy images: alberta 1, alberta 2, alberta 3, canon, cones, factory, forest, grain, pumpkins, stadium, swan and train.

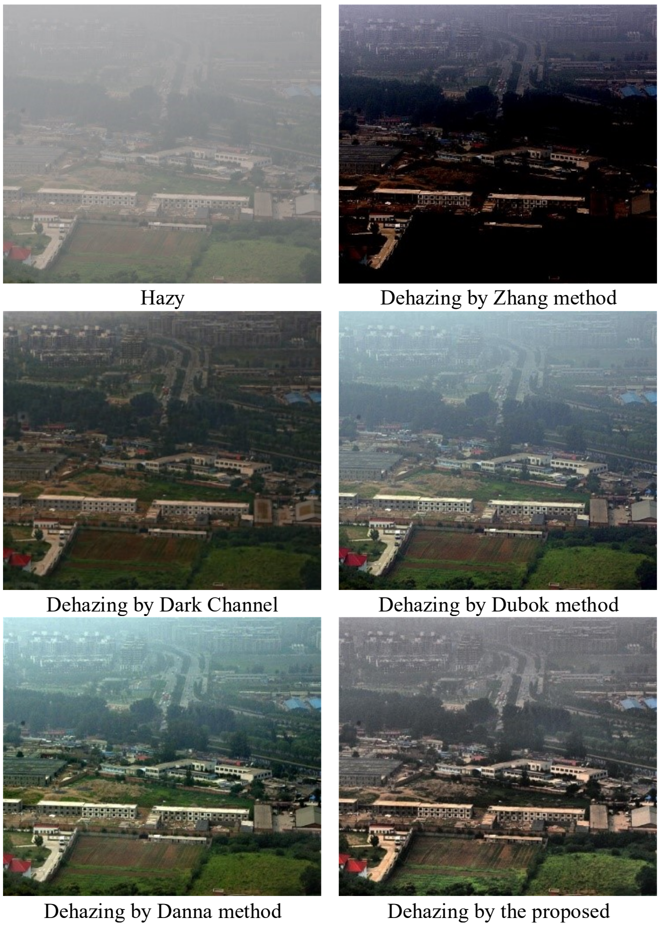

Fig. 3. Dehazing results by the methods for the canon image. NIQE score of the methods: Zhang is 3.6335, Dark Channel is 2.6179, Dubok is 2.6309, Danna is 2.5606 and the proposed is **2.5293**.

C. Experimental Results and Disscusion

We test the proposed dehazing method on 12 selected images. We compare dehazing result with other methods such as method with combination of Retinex and wavelet transform of Zhang et al. [4], dehazing method based on Dark channel [13], dehazing with image entropy and information fidelity of Dubok et al. [12] and non-local dehazing of Danna et al. [9].

Firstly, we test on the canon image. Dehazing results are presented in Figure 3. Haze limits visible distance. In dehazing result by Zhang method, buildings are clearer, but grasslands are too dark, and we cannot differentiate grasses and lands. For Dubok and Danna methods, little hazes still remain. Dehazing result by Danna method is better than the one of Dubok method. For Dark channel, dehazing result is very good, but the result is slightly dark. Otherwise, Dark channel method improved saturation much. Dehazing result by our method is excellent. We can see the distant buildings clearly. Color balancing is preserved well. NIQE score of our method is the lowest (the best): Zhang is 3.6335, Dark Channel is 2.6179, Dubok is 2.6309, Danna is 3.0876 and the proposed is **2.5293**.

For the factory image, dehazing results are presented in Figure 4. Dehazing results by Zhang method and Dark channel are too dark. Dubok and Danna methods give better dehazing results, but some objects near the door such as the black box are not clearly visible. Dehazing result by our method is the best. NIQE score of the proposed method is also the lowest: Zhang is 4.5592, Dark Channel is 4.5222, Dubok is 4.9499, Danna is 4.6409, the proposed is **4.0747**.

Fig. 4. Dehazing results by the methods for the factory image. NIQE score of the methods: Zhang is 4.5592, Dark Channel is 4.5222, Dubok is 4.9499, Danna is 4.6409, the proposed is **4.0747**.

Figure 5 presents dehazing results for the train image. Dehazing results by Zhang method and Dark channel are too dark. Haze remains on result of Dubok method. Dehazing result by Danna method is very good, but details are not clear. Our method acquired the best result. NIQE score of our method is the lowest: Zhang is 3.1487, Dark Channel is 3.1277, Dubok is 2.8535, Danna is 2.5524, the proposed is **2.3088**.

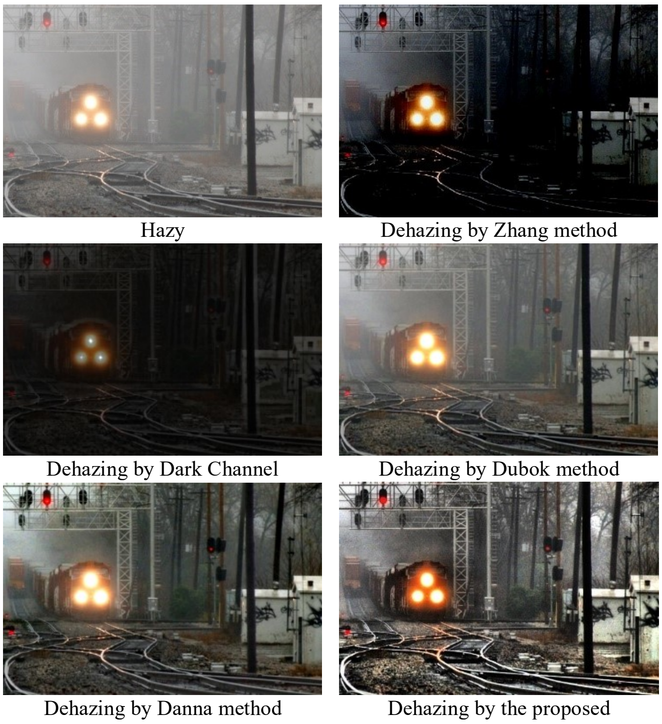

Fig. 5. Dehazing results by the methods for the train image. NIQE score of the methods: Zhang is 3.1487, Dark Channel is 3.1277, Dubok is 2.8535, Danna is 2.5524, the proposed is **2.3088**.

Fig. 6. Dehazing results by the methods for the forest image. NIQE score of the methods: Zhang is 2.7785, Dark Channel is **2.4261**, Dubok is 2.7425, Danna is 2.8664, the proposed is 3.3858.

Fig. 7. Dehazing results by the methods for the alberta 3 image. NIQE score of the methods: Zhang is 5.5788, Dark Channel is 3.8039, Dubok is 3.6406, Danna is 3.53, the proposed is **3.1871**.

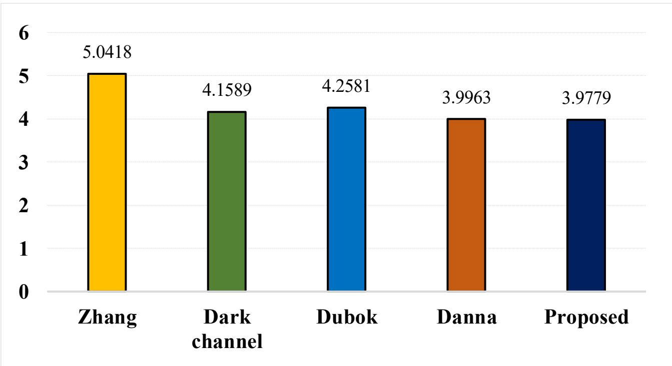

Fig. 8. Average NIQE score comparison of the methods.

Figure 6 presents dehazing results for the forest image. Dehazing result by Zhang method is too dark. A lot of hazes remain in result of Dubok method. Dark channel darkened scene and created artificial effects on leaves and branches of trees (middle regions). Dehazing results by Danna method and our method are excellent. Details in the result by our method are clearer than by Danna method. NIQE score of the methods: Zhang is 2.7785, Dark Channel is **2.4261**, Dubok is 2.7425, Danna is 2.8664, the proposed is 3.3858. For this case, it is very difficult to explain NIQE score, since by NIQE, Dark channel method gives the best dehazing result. Even so, we can see clearly that, dehazing result by Dubok method, Danna method and our method are better than one of dark channel. However, as we mentioned above, in some cases, NIQE score may reflect inexactly image quality assessment like by human eyes.

Dehazing results for the alberta 3 image are presented in Figure 7. Dehazing result by Zhang method is too dark. Dark channel created artificial effects: white lines around trees, windows, doors. Dubok and Danna methods give impressive results. Dehazing result by our method is excellent. The right part of the house in the result by our method is clearer than one by Dubok and Danna methods. NIQE score of the methods: Zhang is 5.5788, Dark Channel is 3.8039, Dubok is 3.6406, Danna is 3.53, the proposed is **3.1871** (the lowest).

Figure 8 shows average NIQE score comparison for all dehazing methods with the selected images. As can be seen, NIQE score of the proposed method is the lowest followed by Danna method. The difference of average NIQE score of our method and Danna method is small, but difference of visual dehazing results are much.

About execution time, our method works very fast. It only takes under 1 second to dehaze on an HD image. Other methods take around 2-5 seconds.

IV. CONCLUSIONS

In this paper, we have proposed a single image dehazing method based on combination of adaptive histogram equalization, HSV color space and linearization of Gamma correction. Our proposed method is simple to implement, but it works very effectively. Otherwise, the proposed method can dehaze very fast that is suitable to video sequence data.

In future, we would like to focus on dehazing on real-time video to integrate on camera system of cars to improve visibility for drivers during the fog.

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